Protein fractionation byproduct from canola meal for dairy cattle

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ABSTRACT

Fiber-protein is a byproduct arising from a process for fractionating high-quality protein from canola meal. The objective of this study was to evaluate the fiber-protein fraction by examining the chemical profiles, rumen degradation, and intestinal digestive characteristics and determining the nutritive value of the fiber-protein fraction as dietary components for dairy cattle in comparison with commercial canola meal and soybean meal. Available energy values were estimated based on National Research Council guidelines, whereas total true protein content potentially absorbable in the small intestine (DVE) were predicted using the predicted DVE/degraded protein balance (OEB) model. The results show that fiber-protein was a highly fibrous material [neutral detergent fiber (NDF): 556; acid detergent fiber (ADF): 463; acid detergent lignin: 241 g/kg of dry matter (DM)] compared with canola meal (NDF: 254; ADF: 212; acid detergent lignin: 90 g/kg of DM) due to the presence of a higher level of seed hulls in fiber-protein. Compared with canola meal, fiber-protein contained 90 g/kg of DM less crude protein (CP), 25% of which consisted of undegradable acid detergent-insoluble CP. Most of the ruminally undegradable nutrient components present in canola meal appeared to be concentrated into fiber-protein during the manufacturing process and, as a result, fiber-protein showed a consistently lower effective degradability of DM, organic matter, CP, NDF, and ADF compared with both canola meal and soybean meal. Available energy content in fiber-protein contained two-thirds of that of canola meal. The DVE was one-third that of soybean meal and one-fifth that of canola meal [DVE value: 58 vs. 180 (soybean) and 291 g/kg of DM (canola meal)]. The OEB value of fiber protein was positive and about half of that of soybean and canola meal [OEB

value: 74 vs. 162 (soybean) and 137 g/kg of DM (canola meal)]. Fiber-protein can be considered as a secondary source of protein in ruminant feed.

Key words: protein fractionation, fiber-protein, metabolizable protein supply, degradable protein balance

INTRODUCTION

Recently, studies have been done to develop processing technologies to fractionate oil-extracted canola meal with the intention of developing feed products for specific feed markets, including a cost-effective alternative for animal-based protein such as fish meal (Mwachireya et al., 1999; Thiessen et al., 2004). In one such study, the meal portion of canola was fractionated to extract protein concentrates (Figure 1). In this process, in addition to the protein concentrates (soluble protein concentrate and insoluble protein concentrate), 2 other products are fractionated. These are fiber-protein and can-sugar fractions. The fiber-protein contains hulls with some dockage that was present in the raw canola meal, whereas can-sugar contains mainly the water-soluble nonprotein components of canola meal. To obtain the maximum advantage from a commercially operated canola protein fractionation process, it is important to use both fiber-protein and can-sugar (Heendeniya et al., 2010).

The CP content in fiber-protein was reported to be 310 g/kg of DM (MCN Bioproducts Inc., 2005). However, in view of the presence of the high fiber level (NDF 556 g/kg of DM) in fiber-protein, the value of these ingredients in monogastric diets would be limited and the most likely market would be as dietary ingredients for ruminants. However, no information is available on this byproduct, particularly as they relate to the nutritional needs of ruminant animals. The objective of this study was to systematically evaluate fiber-protein as feed ingredient in ruminant diets in terms of 1) chemical profiles, 2) energy value, 3) rumen degradation characteristics, 4) intestinal digestion, and 5) modeling the nutrient supply of the fiber-protein fraction as dietary components for dairy cattle in comparison with commercial canola meal and soybean meal.

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Figure 1. Processing and fractionation of canola seeds. Color version available in the online PDF.

MATERIALS AND METHODS

Chemical Characterization

Samples from 3 batches of canola meal and soybean meal were obtained from a commercial supplier (Federated Co-operatives Ltd., Saskatoon, SK, Canada). Three separate samples of fiber-protein were collected from MCN Bioproducts Inc. (Saskatoon, SK, Canada). This sample was dried and in a powder form. All samples were ground through a 1-mm screen using a laboratory-scale centrifugal mill [Retsch ZM-1; Brinkmann Instruments (Canada) Ltd., Mississauga, ON, Canada] before chemical analysis. Samples for starch analysis were ground through a 0.5-mm screen.

Samples were analyzed according to the Association of Official Analytical Chemists (AOAC, 1990) for DM (method 930.15), ether extract (**EE**; method 920.39), CP (Kjeldahl method, using a Kjeltac 2400 autoanalyzer; Foss Analytical A/S, Hillerød, Denmark), ash (method 924.05), ADF (method 973.18, using an Ankom 200 fiber analyzer; Ankom Technology, Macedon, NY) and ADL (ADF method 973.18, followed by 720 g/kg of H₂SO₄ treatment). The NDF content was determined with heat-stable α -amylase but without sodium sulfite according to the procedure proposed by Van Soest et al. (1991). The acid detergent-insoluble CP (**ADIP**) and neutral detergent-insoluble CP (**NDIP**) were determined as per the procedure of Licitra et al. (1996) using the Ankom 200 fiber analyzer, followed by the Kjeldahl method using the Kjeltac 2400 autoanalyzer. Nonprotein nitrogen content was determined by precipitating the true protein (**TP**) fraction with the use of tungstic acid and calculating the difference between total CP and CP content of the precipitate (residual) according to Licitra et al. (1996). To obtain the soluble CP (**SCP**), samples were incubated in bicarbonate-phosphate buffer and then filtered through Whatman no. 54 filter paper and the residue was analyzed for Kjeldahl CP content. The SCP was calculated as the difference between total CP and residual CP as proposed by Roe et al. (1990). The α -amylase amyloglucosidase method was used to determine the starch content of samples (Megazyme total starch assay kit; Megazyme International Ireland Ltd., Bray, Co. Wicklow, Ireland). The total carbohydrate (**CHO**) and NFC contents were calculated according to equations suggested by NRC (2001). The Cornell Net Carbohydrate and Protein System (**CNCPS**) procedure proposed by Sniffen et al. (1992) was used to partition the total CP content into fraction PA, PB, and PC. The PB fraction was partitioned further into 3 subfractions: PB1, PB2, and PB3 (PA = fraction of CP that is instantaneously

solubilized at time zero; PB1 = fraction of CP that is soluble in borate-phosphate buffer and precipitated with trichloroacetic acid; PB2 = intermediately degradable protein fraction; PB3 = slowly degradable protein fraction; PC = fraction of CP recovered with ADF and considered to be undegradable).

In Situ Rumen Incubation

The same feed samples used for chemical analysis were used for in situ study; however, without grinding. Two nonlactating Holstein-Friesian cows weighing approximately 650 kg and ruminally fistulated with 10-cm cannulas (Bar Diamond Inc., Parma, ID) were used. The cows were individually fed a balanced TMR (15 kg/d as fed) that contained 600 g of barley silage/kg (approximately 350 g/kg of DM), 260 g/kg of standard dairy concentrate (containing barley, wheat, oats, soybean meal, canola meal, minerals, and vitamins), 100 g of alfalfa hay/kg, and 40 g of alfalfa dehydrate/kg. The animals were fed twice daily at 0800 and 1600 h, housed in individual pens (size 6 $\times$ 9 m) with free access to water and an exercise area. They were cared for according to the guidelines of the Canadian Council on Animal Care (1993).

The nylon bags were made out of Nitex nylon material (Screen Tech Inc., San Jose, CA) with a pore size of 40 μ m. The bags (10 $\times$ 20 cm) were stitched with a nylon thread and needle holes were sealed with waterproof and nondegradable glue. The approximate sample weight was 7 g per bag and the sample weight-to-bag surface area ratio was 35 to 39 mg/cm². The maximum number of bags placed in the rumen at any time was 30. Weighted polyester mesh bags were used to hold the nylon bags in place within the rumen. Incubations were carried out for 72, 48, 24, 12, 8, 4, 2, and 0 h on a gradual addition-all out schedule. All treatments (9 feed samples from 3 different feed types) were randomly allocated to 2 animals as per each incubation duration. The experiment was repeated over 3 periods/run consecutively. Upon removal of bags from the rumen, they were immediately rinsed under a cold stream of water to prevent further microbial degradation and to remove excess ruminal contents.

All of the bags, including those representing 0 h, were then hand-rinsed in a plastic tub filled with cold tap water until the rinse water was clear. The bags were laid flat on metal trays, once the excess water was drained out and the bags were dried in a forced-air oven at 55°C for 48 h. At the end of drying, residues were pooled together as per treatment, duration of incubation, and period/run for analysis of DM, OM, CP, NDF, and ADF.

Rumen degradation parameters for DM, OM, CP, NDF, and ADF were determined by using the first-order rumen degradation kinetic equation proposed by Ørskov and McDonald (1979), modified with inclusion of lag time (Robinson et al., 1986; Dhanoa, 1988):

$$R(t) = U + (100 - S - U) \times e^{-K_d(t-T_0)},$$

where $R(t)$ = residue percentage at t hours of incubation, U = undegradable fraction (%), S = water-soluble fraction (%), K_d = degradation rate (%/h), and T_0 = lag time (h). The potentially degradable fraction (D) = $100 - S - U$. The iterative nonlinear regression procedure (PROC NLIN-Gauss-Newton method of SAS; SAS Institute Inc., Cary, NC) was used to fit data to the model.

The effectively degradable fractions (ED) and ruminally undegradable fractions (RU) of each nutrient were calculated using the following equations (NRC, 2001; Yu et al., 2003a,b):

$$ED = S + D \times \left(\frac{K_d}{K_d + K_p} \right);$$

$$RU = U + D \times \left(\frac{K_p}{K_d + K_p} \right),$$

where K_p is the outflow of digesta from rumen, which was assumed to be equal to 6%/h (Tamminga et al., 1994; Yu et al., 2003b).

In situ samples were prepared for chemical analysis by grinding to pass through a 1-mm screen, using a laboratory-scale mill [Retsch ZM-1; Brinkmann Instruments (Canada) Ltd.].

Energy Value Estimation

The gross energy value of feed samples was determined with the use of a bomb calorimeter (Parr 1281; Parr Instruments Co., Moline, IL). The TDN, digestible energy (DE), ME, and net energy (NE) values were calculated using a summary approach according to NRC (2001).

Prediction of Microbial Protein Synthesis and Potential Protein Supply to the Small Intestine

The total TP content potentially absorbable in the small intestine/degraded protein balance (DVE/OEB) model (Tamminga et al., 1994) was used to predict the DVE values and OEB value.

Statistical Analysis

Chemical Profile, Energy Value, and Protein Subfraction Studies. Statistical analyses were performed using the MIXED procedure of SAS (version 9.1.3; SAS Institute Inc.). The model used for the analysis was $Y_{ij} = \mu + T_i + e_{ij}$, where Y_{ij} is an observation of the dependent variable ij ; μ is the population mean for the variable; T_i is the effect of the feed type as a fixed effect, the 3 batches as replicates; and e_{ij} is the random error associated with the observation ij .

Rumen Degradation, Intestinal Digestion, and Modeling Nutrient Supply Studies. Statistical analyses were performed using the MIXED procedure of SAS (version 9.1.3; SAS Institute Inc.). The model used for the analysis was $Y_{ijk} = \mu + T_i + S_k + e_{ijk}$, where Y_{ijk} is an observation of the dependent variable ijk , μ is the population mean for the variable, T_i is the effect of the feed type as a fixed effect, S_k is the run effect as a random effect, and e_{ijk} is the random error associated with the observation ijk .

For all statistical analyses, significance was declared at $P < 0.05$. Differences among the treatments were evaluated using a multiple comparison test following the Tukey method.

RESULTS AND DISCUSSION

Chemical Composition Profiles and Characteristics

The canola seed fractionation, a proprietary process developed by MCN Bioproducts Inc., is illustrated in Figure 1. The fiber-protein had a higher OM content (957 g/kg of DM) compared with both canola and soybean meal (Table 1). The fiber-protein is the residue of the protein fractionation process and consists mainly of hulls separated after aqueous filtration. The EE content was very low (i.e., 10 g/kg of DM or less) in all of the ingredients except for canola meal (53 g/kg of DM), which was similar to the average EE content reported by NRC (2001). The EE content (15 g/kg of DM) is low in comparison to that found in canola hulls (130 g/kg of DM) by McKinnon et al. (1995). In this latter study, the high EE content of the hulls is likely a reflection of seed kernels present in the hulls due to the front-end dehulling process used by these researchers.

The total CHO content (632 g/kg of DM) in the fiber-protein was higher ($P < 0.05$) than in canola meal and soybean meal by 165 and 221 g/kg of DM, respectively. The NFC in the fiber-protein was the lowest (202 g/kg of DM) and different ($P < 0.05$) from canola meal (293 g/kg of DM) and soybean meal (366 g/kg of DM). In fiber-protein, NFC amounts to only 320 g/kg of total CHO, whereas NFC represents 629 g/kg and 890 g/kg

Table 1. Dry matter, ash, OM, ether extract, and carbohydrate composition of fiber-protein compared with commercial soybean meal and canola meal

Component	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
DM (g/kg)	918	902	921	16.8
Ash (g/kg of DM)	43 ^b	84 ^a	94 ^a	13.1
OM (g/kg of DM)	957 ^a	916 ^b	906 ^b	13.1
Ether extract (g/kg of DM)	15 ^b	53 ^a	11 ^b	3.8
Carbohydrates (CHO)				
Total CHO (g/kg of DM)	632 ^a	467 ^b	411 ^c	6
Starch (g/kg of DM)	8	10	10	1.6
NFC (g/kg of DM)	202 ^c	293 ^b	366 ^a	13.6
NFC (g/kg of CHO)	320 ^c	629 ^b	890 ^a	29
NDF (g/kg of DM)	556 ^a	254 ^b	88 ^c	17.1
ADF (g/kg of DM)	463 ^a	212 ^b	61 ^c	16.2
ADL (g/kg of DM)	241 ^a	90 ^b	6 ^c	14.7
Hemicellulose ¹ (g/kg of DM)	93 ^a	42 ^b	27 ^c	2
Cellulose ² (g/kg of DM)	222 ^a	122 ^b	55 ^c	6.5

^{a-c}Means within a row with the same superscripts are not significantly different ($P > 0.05$).

¹Hemicellulose = NDF – ADF.

²Cellulose = ADF – ADL.

of total CHO in canola meal and soybean meal, respectively. When the nonfiber content in the fiber-protein is compared with canola meal, it seems that structural carbohydrates in canola meal were isolated mostly into fiber-protein during the fractionation process.

The structural CHO content observed for canola meal in this study agrees with values reported in other publications (Mustafa et al., 1996; NRC, 2001; Mae-soomi et al., 2006). Significantly higher NDF and ADF contents were observed in the fiber-protein relative to canola meal (556 vs. 254 and 463 vs. 212 g/kg of DM, respectively), which could be attributed to high level of hulls present in fiber-protein. McKinnon et al. (1995) reported a similar ADF content (467 g/kg of DM) but higher NDF content (658 g/kg of DM) for untreated canola hulls obtained from front-end dehulling.

Very ADL content (6 g/kg of DM) was observed in soybean meal. In comparison to canola meal, both cellulose and ADL content were almost doubled in fiber-protein (122 vs. 222 and 90 vs. 241 g/kg of DM, respectively), indicating that both cellulose and lignin are closely associated with the hulls of canola seed. A similar association between canola seed hull and cellulose/lignin was reported previously by Mustafa et al. (1996). In the CNCPS, indigestible carbohydrate is estimated by multiplying ADL by 2.4 (Sniffen et al., 1992; Fox et al., 2004). If the same principal is applied here, it would indicate that the NDF (556 g/kg of DM) fraction of the fiber-protein fraction would be totally indigestible (i.e., $2.4 \times 241 = 578 > 556$ g/kg of DM). This is comparable with a high indigestible NDF content in canola meal (estimated as 850 g/kg of DM). The highest CP content was observed in soybean meal

(484 g/kg of DM), followed by canola meal (396 g/kg of DM), and fiber-protein (309 g/kg of DM; Table 2). McKinnon et al. (1995) reported a protein content of 154 g/kg of DM in canola hulls obtained from front-end dehulling, which is only half that of the value for fiber-protein and less than half of that for canola meal. The difference of 90 g/kg ($P < 0.05$) in CP content observed in fiber-protein compared to canola meal could, therefore, be attributed to the concentration of hulls in fiber-protein. On the other hand, fiber-protein also contains parts of the seed other than hulls, which could contribute to the protein content of 309 g/kg of DM observed in the current study.

No difference ($P > 0.05$) was observed in the SCP content of fiber-protein and canola meal, which was about 250 g/kg of total CP, whereas SCP content in soybean meal ($P < 0.05$) was only 144 g/kg of total CP. In the manufacturing process, most of the available TP was separated as protein concentrates. On a DM basis, NPN content in fiber-protein (43 g/kg of DM) was less ($P < 0.05$) than that of canola meal (71 g/kg of DM). However, when the share of NPN in CP was considered, there was no difference ($P > 0.05$) between fiber-protein (139 g/kg of CP) and canola meal (178 g/kg of CP).

The protein fraction associated with the NDF and ADF in fiber-protein was higher than ($P < 0.05$) that of canola meal by 200 and 170 g/kg of DM, respectively. This difference is likely due to the presence of hulls in fiber-protein. The lowest ($P < 0.05$) NDIP and ADIP contents were observed in soybean meal (89 and 14 g/kg of CP, respectively). The CP associated with ADF is considered indigestible and the TP fraction is consid-

Table 2. Crude protein and protein fractions in fiber-protein compared with commercial soybean meal and canola meal

Component	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
CP (g/kg of DM)	309 ^c	396 ^b	484 ^a	10.1
SCP ¹ (g/kg of DM)	83 ^{ab}	100 ^a	70 ^b	9.4
SCP (g/kg of CP)	267 ^a	252 ^a	144 ^b	20
NPN ² (g/kg of DM)	43 ^b	71 ^a	25 ^b	9.3
NPN ² (g/kg of CP)	139 ^a	178 ^a	51 ^b	19.8
NPN ² (g/kg of SCP)	520 ^{bc}	706 ^{ab}	336 ^c	73.8
NDIP ³ (g/kg of DM)	126 ^a	80 ^b	43 ^c	12.8
NDIP (g/kg of CP)	409 ^a	202 ^b	89 ^c	38.9
ADIP ⁴ (g/kg of DM)	77 ^a	32 ^b	7 ^b	9.3
ADIP (g/kg of CP)	249 ^a	82 ^b	14 ^b	30.4
True protein (g/kg of CP)	612 ^c	748 ^b	945 ^a	29.3

^{a-c}Means within a row with the same superscripts are not significantly different ($P > 0.05$).

¹Soluble CP.

²Nonprotein nitrogen is presented as CP ($6.25 \times \text{N}$).

³Neutral detergent-insoluble CP.

⁴Acid detergent-insoluble CP.

ered as the portion of CP without NPN and ADIP. In the CNCPS, this true protein fraction, known as the PB fraction, is subdivided into 3 fractions: PB1, PB2, and PB3 (Sniffen et al., 1992). In the current study (Table 3), it was observed that a difference ($P < 0.05$) existed in TP content between different feed ingredients, where the highest level of TP (in total protein) was present in soybean meal (945 g/kg of CP), followed by canola meal (748 g/kg of CP) and fiber-protein (612 g/kg of CP). The TP values of canola meal and soybean meal agree with those reported previously (Mustafa et al., 1996; NRC, 2001). The indigestible protein fraction PC in fiber-protein amounted to approximately 250 g/kg of its total CP and it was higher ($P < 0.05$) than in other feed ingredients. On a DM basis, no significant difference existed in the soluble TP fraction PB1 between fiber-protein and canola meal, which indicates that an equal proportion of PB1 was separated with dewatered cake as with the aqueous extract during the extraction stage in the manufacturing process. This, in turn, resulted in a higher ($P < 0.05$) concentration of PB1 (on the basis of CP and TP) in fiber-protein (128 g/kg of CP and 210 g/kg of TP) compared with canola meal (73 g/kg of CP and 97 g/kg of TP). The PB2 fraction was the largest protein fraction. The PB2 fraction of soybean meal was larger than ($P < 0.05$) that of the other 2 ingredients on both a DM and CP bases. However, no difference ($P > 0.05$) was found in the concentration of PB2 in relation to TP between canola meal (743 g/kg of TP) and soybean meal (823 g/kg of TP). The slowly degradable PB3 fraction was observed to be higher in both fiber-protein and canola meal than that of soybean meal. No significant difference in PB3 concentration was observed between canola meal (49

g/kg of DM) and fiber-protein (48 g/kg of DM). The degradation rates of PB1, PB2, and PB3 were reported to be 135 to 350%/h, 3 to 6%/h, and 0.05 to 0.55%/h, respectively (Sniffen et al., 1992; Fox et al., 2000). Based on these degradation rates and the distribution of 3 subfractions in each ingredient, soybean meal can be expected to show faster ruminal degradability compared with canola meal and fiber-protein.

In Situ Rumen Degradation Characteristics

In Situ Rumen Kinetic Parameters and Degradability of DM. As shown in the Table 4, the soluble fraction (**S**) of DM in fiber protein was 70 g/kg, which amounts to only one-third of that of canola meal (211 g/kg). No difference ($P > 0.05$) was found in the S fraction between canola and soybean meal. The potentially degradable fraction (**D**) of DM in soybean meal (730 g/kg) was higher ($P < 0.05$) than that in canola meal (641 g/kg), whereas a far greater difference in D was observed between fiber-protein (455 g/kg) and canola meal. The S and D fraction concentrations of canola and soybean meal agree with those reported by Kirkpatrick and Kennelly (1987), whereas Mustafa (1996) reported a similar value for regular canola meal. Woods et al. (2003), in their study, reported a slightly larger S fraction (330 g/kg) and slightly larger D fraction (650 g/kg) for soybean meal DM. Use of nylon bags with a larger pore size (50 μm) by Woods et al. (2003) could be one of the reasons for having a larger S fraction. However, the total degradable fraction (**S** + **D**) of DM in soybean meal reported by these researchers (970 g/kg) is in agreement with findings of the current study (960 g/kg).

Table 3. Protein fractions (associated with rumen degradation characteristics) of fiber-protein compared with commercial soybean meal and canola meal

Protein fraction ¹	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
g/kg of CP				
PA	139 ^a	169 ^a	41 ^b	19.4
PB1	128 ^a	73 ^b	92 ^{ab}	15.6
PB2	324 ^c	555 ^b	778 ^a	32.2
PB3	159 ^a	120 ^{ab}	75 ^b	185
PC	249 ^a	82 ^b	14 ^b	30.4
True protein (TP)	612 ^c	748 ^b	945 ^a	29.3
g/kg of TP				
PB1	210 ^a	97 ^b	98 ^b	17.9
PB2	526 ^b	743 ^a	823 ^a	29.8
PB3	264 ^a	160 ^b	79 ^b	32.3
g/kg of DM				
PA	43 ^{ab}	68 ^a	20 ^b	9.0
PB1	40	29	45	4.6
PB2	100 ^c	220 ^b	376 ^a	9.4
PB3	49	48	36	7.9
PC	77 ^a	32 ^b	7 ^b	0.93

^{a-c}Means with the same superscripts in the same row are not significantly different ($P > 0.05$).

¹PA = fraction of CP that is instantaneously solubilized at time zero; PB1 = fraction of CP that is soluble in borate-phosphate buffer and precipitated with trichloroacetic acid; PB2 = intermediately degradable protein fraction; PB3 = slowly degradable protein fraction; PC = fraction of CP recovered with ADF and considered to be undegradable.

Almost half of the DM in fiber-protein was ruminally undegradable (475 g/kg), whereas only 148 g/kg and 40 g/kg of DM were found to be undegradable in canola meal and soybean meal, respectively. The differences in parameters among the test ingredients can be attributed partly to the presence of seed hull, which was reflected by the lignin content of the test feeds. Canola meal, having a higher lignin content than soybean meal (90 vs. 6 g/kg), contains about 300 g of hulls/kg (Bell and Shires, 1982; Bell, 1993), whereas fiber-protein, by nature of its manufacturing process, tends to contain a much higher level of hulls, which is indicated by its higher lignin content (241 g/kg). The degradation rate (K_d) of DM in the fiber-protein (9.9%/h) was closer to that of canola meal (9.0%/h). This is within the range of K_d for DM reported by Mustafa (1996), varying from

8.2 to 11.2%/h for canola meal obtained from different sources.

The K_d values between soybean meal and fiber-protein were different ($P < 0.05$). Kirkpatrick and Kennelly (1987) reported similar K_d values for canola meal and soybean meal, whereas slightly higher values of 15.1 and 11.6%/h were reported by Khorasani et al. (1993) and Mustafa (1996), respectively.

At a ruminal passage rate (K_p) of 6%/h, 645 g/kg of DM in soybean meal was effectively degradable in the rumen and not significantly different from the effectively degradable DM (**EDDM**) of canola meal (594 g/kg DM). These values are comparable with EDDM values reported by Kirkpatrick and Kennelly (1987) for canola meal (630 to 640 g/kg of DM) and soybean meal (670 to 690 g/kg of DM) at a 5.0%/h K_p . The EDDM value

Table 4. In situ rumen degradation kinetics of DM of fiber-protein in comparison with commercial canola meal and soybean meal

Parameter ¹	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
S (g/kg of DM)	70 ^b	211 ^a	230 ^a	7.1
D (g/kg of DM)	455 ^c	641 ^b	730 ^a	22.0
U (g/kg of DM)	475 ^a	148 ^b	40 ^c	25.6
K_d (%/h)	9.9 ^a	9.0 ^{ab}	7.9 ^b	0.49
T0 (h)	0.20	0.01	0.25	0.086
EDDM (g/kg of DM)	353 ^b	594 ^a	645 ^a	19.8
RUDM (g/kg of DM)	647 ^a	406 ^b	355 ^b	19.8

^{a-c}Means within a row with the same superscripts are not significantly different ($P > 0.05$).

¹S = water-soluble fraction; D = potentially degradable fraction; U = undegradable fraction; K_d = degradation rate; T0 = lag time; EDDM = effectively degradable DM; RUDM = ruminally undegradable DM.

obtained for canola meal in the current study was closer to that of rapeseed meal (612 g/kg of DM at a 6.0%/h K_p) as reported by Woods et al. (2003) but slightly lower than that (665 to 696 g/kg of DM at a 5.0%/h K_p) reported by Mustafa (1996). In fiber-protein, only 353 g/kg of DM was ruminally degradable and lower ($P < 0.05$) than both canola meal and soybean meal. McKinnon et al. (1995) reported EDDM values of 310 and 400 g/kg of DM, respectively, for defatted and untreated canola hulls (from front-end dehulling) at a K_p value of 5.0%/h. These values are closer to EDDM content in fiber-protein, which has been calculated at a 6.0%/h K_p in the current study.

In Situ Rumen Kinetic Parameters and Degradability of OM. Rumen kinetic parameters for OM were similar to that of DM (Table 5). The S fraction of OM in fiber-protein (60 g/kg) was smaller ($P < 0.05$) than that of canola meal (205 g/kg) and soybean meal (190 g/kg), with no difference ($P > 0.05$) between canola and soybean meal. The largest D fraction was observed ($P < 0.05$) in soybean meal (805 g/kg), followed by canola meal (642 g/kg) and fiber-protein (465 g/kg). Only 5 g/kg of the undegradable fraction of OM was observed in soybean meal compared to 153 g/kg in canola meal. The undegradable OM fraction in fiber-protein (475 g/kg) was approximately 3 times that of the undegradable fraction in canola meal.

No difference ($P > 0.05$) was observed in the K_d of the D fraction between canola meal (9.1%/h) and fiber-protein (9.8%/h). However, the K_d for soybean meal (7.5%/h) was lower ($P < 0.05$) than the K_d of both canola meal and fiber-protein. This is in contrast to results reported by Woods et al. (2003), who reported a higher K_d for soybean meal (12.0%/h) than rapeseed meal (9.0%/h). A significantly longer lag time (T0) was observed with OM degradation in soybean meal (0.26 h) compared to canola meal (0.00 h). The differences in T0 between fiber-protein (0.08 h) and soybean meal

(0.26) as well as between fiber-protein and canola meal were not different ($P > 0.05$). Out of the total OM, only 348 g/kg of OM was degradable in fiber-protein, which was significantly lower ($P < 0.05$) than canola (591 g/kg of OM) and soybean meal (637 g/kg of OM). The difference between soybean meal and canola meal, however, was not different ($P > 0.05$). The effectively degradable OM content in fiber-protein comprised one-third of DM (333 g/kg of DM), which was lower ($P < 0.05$) than that of canola meal (548 g/kg of DM) and soybean meal (561 g/kg of DM).

Approximately 25 g/kg more ruminally undegradable OM was present in the fiber-protein compared with canola meal. The presence of lignin at a comparatively higher level in fiber-protein (241 g/kg of DM) can be attributed to the higher ruminally undegradable OM content found in fiber-protein (624 g/kg of DM).

In Situ Rumen Kinetic Parameters and Degradation of CP. As shown in Table 6, the smallest soluble fraction (S) was observed in soybean meal (7 g/kg), whereas canola meal had the largest (119 g/kg). The S fraction in fiber-protein (62 g/kg) was about 50% that of canola meal. The K_d was highest in fiber-protein (15.0%/h), followed by canola meal (10.9%/h) and soybean meal (7.2%/h). These K_d of canola meal and soybean meal closely agree with those reported in NRC (2001).

The K_d value represents the overall degradation rate of the B fraction of the CP (PB) and depends on the makeup of the B-fraction, as the different subfractions of PB (PB1, PB2, and PB3) have different rates of degradation. Hence, the differences in makeup of the PB fraction in the different ingredients could be attributed partly to differences in K_d values for protein observed in the current study. No lag time (T0) was observed for in situ degradation of protein in fiber-protein or canola meal, whereas a short T0 (0.39 h) was observed in soybean meal. The undegradable fraction (U) in fiber-

Table 5. In situ rumen degradation kinetics of OM of fiber-protein in comparison with commercial canola meal and soybean meal

Component ¹	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
S (g/kg of OM)	60 ^b	205 ^a	190 ^a	7.1
D (g/kg of OM)	465 ^c	642 ^b	805 ^a	22.2
U (g/kg of OM)	475 ^a	153 ^b	5 ^c	25.8
K_d (%/h)	9.8 ^a	9.1 ^a	7.5 ^b	0.50
T0 (h)	0.08 ^{ab}	0.0 ^b	0.26 ^a	0.068
EDOM (g/kg of OM)	348 ^b	591 ^a	637 ^a	19.9
EDOM (g/kg of DM)	333 ^b	548 ^a	561 ^a	18.8
RUOM (g/kg of OM)	652 ^a	409 ^b	363 ^b	19.9
RUOM (g/kg of DM)	624 ^a	379 ^b	320 ^b	19.3

^{a-c}Means within a row with the same superscripts are not significantly different ($P > 0.05$).

¹S = water-soluble fraction; D = potentially degradable fraction; U = undegradable fraction; K_d = degradation rate; T0 = lag time; EDOM = effectively degradable OM; RUOM = ruminally undegradable OM.

Table 6. In situ rumen degradation kinetics of CP of fiber-protein in comparison with commercial canola meal and soybean meal

Component ¹	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
S (g/kg of CP)	62 ^b	119 ^a	7 ^c	10.3
D (g/kg of CP)	548 ^c	811 ^b	993 ^a	29.9
U (g/kg of CP)	389 ^a	70 ^b	0.0 ^b	35.3
K _d (%/h)	15.0 ^a	10.9 ^b	7.2 ^c	0.71
T0 (h)	0.0 ^b	0.0 ^b	0.39 ^a	0.047
EDCP (g/kg of CP)	455 ^b	642 ^a	547 ^a	30.4
EDCP (g/kg of DM)	141 ^b	265 ^a	256 ^a	10.3
RUCP (g/kg of CP)	545 ^a	358 ^b	453 ^b	30.4
RUCP (g/kg of DM)	168 ^b	148 ^b	212 ^a	9.5

^{a-c}Means within a row with the same superscripts are not significantly different ($P > 0.05$).

¹S = water-soluble fraction; D = potentially degradable fraction; U = undegradable fraction; K_d = degradation rate; T0 = lag time; EDCP = effectively degradable CP; RUCP = ruminally undegradable CP.

protein (389 g/kg) was higher ($P < 0.05$) than that of canola meal and soybean meal. Similar U values for soybean meal were observed by Kirkpatrick and Kennelly (1987) and for canola meal by Kirkpatrick and Kennelly (1987), Khorasani et al. (1993), and Mustafa (1996).

It was reported that ADIP content has a negative correlation with CP degradation (Van Soest 1994; McKinnon et al., 1995; NRC, 2001). Similarly, the differences in U values observed between the tested ingredients in the current study were reflected by their indigestible ADIP contents (PC subfractions), where the ADIP content in fiber-protein, canola meal, and soybean meal were, respectively, 249, 82, and 14 g/kg, as shown in Table 2. In canola hulls, the ADIP component in the CP fraction was reported to be as high as 350 g/kg (McKinnon et al., 1995; NRC, 2001). As the fiber-protein is rich in hull, its comparatively higher undegradable protein fraction is possibly due to its higher ADIP content contributed by hulls.

At a K_p of 6.0%/h, the lowest ($P < 0.05$) effectively degradable CP (**EDCP**) was observed in fiber-protein, amounting to 455 g/kg of total CP compared with canola meal (642 g/kg of CP) and soybean meal (547 g/kg of CP). A similar observation was reported by Kirkpatrick and Kennelly (1987), where the EDCP contents of canola meal and soybean meal were 632 g/kg and 602 g/kg, respectively, at a 5.0%/h K_p. The EDCP for canola meal in the current study is comparable with those reported by Mustafa (1996) for canola meal obtained from different sources (from 667 to 682 g/kg at a 5.0%/h K_p). However, Khorasani et al. (1993; 1989) reported >700 g/kg of EDCP in canola meal. The observed EDCP value for fiber-protein is closer to the EDCP value reported by McKinnon et al. (1995) for canola hulls (492 g/kg at a 5.0%/h K_p) indicating a closer resemblance in CP between canola hulls and fiber-protein. On a DM basis, ruminally degradable

CP content in fiber-protein (141 g/kg of DM) was far lower ($P < 0.05$) than that of canola meal (265 g/kg of DM), whereas the difference between canola meal and soybean meal (256 g/kg) was not significant. Out of total CP, 545 g/kg of CP in fiber-protein was ruminally undegradable, which was significantly higher than that of canola meal (358 g/kg of CP) and soybean meal (453 g/kg of CP). However, on a DM basis, the ruminally undegradable CP content in soybean meal (212 g/kg of DM) was higher than ($P < 0.05$) that in both fiber-protein (168 g/kg of DM) and canola meal (148 g/kg of DM), whereas the difference between canola meal and fiber-protein was not significant. Ruminally undegradable CP is the rumen bypass protein that is available for postruminal digestion. Even though the bypass protein content in soybean meal was higher, a major portion of that would be available to the animal postruminally, as CP in soybean meal is almost totally digestible. On the other hand, with a higher undegradable CP fraction (389 g/kg of CP), ruminal bypass protein in fiber-protein would be mostly unavailable to the host animal. Canola meal with only a 70 g/kg undegradable CP fraction would have a comparatively higher amount of available protein postruminally despite its ruminally undegradable CP content being closer to that of fiber-protein. This was further substantiated by the content of the undegradable protein PC fraction in each feed ingredient, as seen in Table 3. The results also have shown a remarkable closeness between the chemically derived PC fraction and the in situ U fraction for both canola meal (8.2 vs. 7.0%) and soybean meal (1.4% vs. 0%) even though the PC fraction in fiber-protein (249 g/kg) was substantially smaller than the U fraction (389 g/kg).

In Situ Rumen Kinetic Parameters and Degradability of NDF. The rumen degradation kinetics of NDF for the different feed ingredients is given in Table 7. The amount of washable NDF was small (less

than 10 g/kg of NDF) in all 3 ingredients and the difference was not significant. However, a difference ($P > 0.05$) was observed among ingredients in the potentially degradable fraction, which in soybean meal (977 g/kg) was 2 times that in canola meal (483 g/kg) and 3 times that in fiber-protein (322 g/kg). Only a small fraction of undegradable NDF was observed in soybean meal (19 g/kg of NDF), whereas 511 g/kg of NDF in canola meal was found to be undegradable. In fiber-protein, 673 g/kg of NDF was found to be undegradable. The degradability of NDF depends on the proportion of its main components (i.e., cellulose, hemicellulose, and lignin). Lignin is known to be highly indigestible and renders the cellulose and hemicellulose associated with it undegradable (Van Soest 1994). The lignin content in fiber-protein, canola meal, and soybean meal was 241, 90, and 6 g/kg of DM, respectively (Table 1). In the CNCPS, undegradable fiber associated with lignin is calculated as $2.4 \times$ lignin. Accordingly, the difference in U fractions in NDF observed among 3 ingredients under in situ conditions can be explained partly by lignin content. The K_d of NDF were not different ($P > 0.05$) among fiber-protein, soybean meal, and canola meal. A lag time of about 1 h or more to commence NDF degradation was observed in all 3 ingredients. At a K_p of 6.0%/h, soybean meal had the highest ($P < 0.05$) effective NDF degradability at 490 g/kg of NDF, followed by canola meal (278 g/kg of NDF) and fiber-protein (197 g/kg of NDF). On a DM basis, the highest ($P < 0.05$) effective degradable NDF was found in fiber-protein (109 g/kg of DM) in comparison with canola meal (65 g/kg of DM) and soybean meal (45 g/kg of DM). This was due to the higher content of NDF in the fiber-protein.

Limited research has been carried out on the degradation of fiber components in concentrate feeds. Mustafa (1996), working on canola meal, reported a

slightly lower degradation rate (5.1%/h) and a longer lag time (2.8 h) for NDF in regular canola meal. He also reported a higher effectively degradable NDF value (460 g/kg) for canola meal at a 5.0%/h K_p , which was possibly due to a difference in the chemical composition, as his canola meal sample had a comparatively lower lignin and higher hemicellulose content. The effectively degradable NDF content in the fiber-protein closely matches values reported by McKinnon et al. (1995) for canola hulls. They reported that untreated canola hulls contained a potentially degradable NDF content of 301 g/kg and an effectively degradable NDF value of 194 g/kg.

In Situ Rumen Kinetic Parameters and Degradability of ADF. The S fractions in all 3 ingredients were insignificant (Table 8). The ADF in soybean meal was completely degradable, which can be expected, as its lignin content was very low (6 g/kg of DM). On the other hand, potentially degradable ADF fractions were lower ($P < 0.05$) in both canola meal (415 g/kg) and fiber-protein (236 g/kg), which are comparatively high in lignin content due to the presence of hulls. The D fraction in the hull-enriched fiber-protein was lower ($P < 0.05$) than that of canola meal, indicating the existence of a comparatively higher percentage of hulls. The K_d values of both canola meal and fiber-protein were similar and significantly different from the K_d value of soybean meal. The lag times of ADF in all 3 ingredients were longer than their respective lag times of NDF, indicating possible differences between hemicellulose and cellulose degradability in the rumen. The effectively degradable ADF in fiber-protein was only 147 g/kg compared with canola meal (251 g/kg) and soybean meal (469 g/kg). The effectively degradable ADF content in canola meal observed in this study is comparable with that reported by Mustafa (1996).

Table 7. In situ rumen degradation kinetics of NDF of fiber-protein in comparison with commercial canola meal and soybean meal

Component ¹	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
S (g/kg of NDF)	5	7	5	5.8
D (g/kg of NDF)	322 ^c	483 ^b	977 ^a	17.8
U (g/kg of NDF)	673 ^a	510 ^b	19 ^c	19.4
K_d (%/h)	9.0 ^a	7.7 ^{ab}	5.9 ^b	0.73
T0 (h)	1.12	1.52	0.86	0.290
EDNDF (g/kg of NDF)	197 ^c	278 ^b	490 ^a	14.9
EDNDF (g/kg of DM)	109 ^a	65 ^b	45 ^c	4.7
RUNDF (g/kg of NDF)	803 ^a	722 ^b	510 ^c	14.9
RUNDF (g/kg of DM)	447 ^a	169 ^b	46 ^c	17.1

^{a-c}Means within a row with the same superscripts are not significantly different ($P > 0.05$).

¹S = water-soluble fraction; D = potentially degradable fraction; U = undegradable fraction; K_d = degradation rate; T0 = lag time; EDNDF = effectively degradable NDF; RUNDF = ruminally undegradable NDF.

Table 8. In situ rumen degradation kinetics of ADF of fiber-protein in comparison with commercial canola meal and soybean meal

Component ¹	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
S (g/kg of ADF)	0.4	4.8	3.3	2.16
D (g/kg of ADF)	236 ^c	415 ^b	997 ^a	18.7
U (g/kg of ADF)	763 ^a	581 ^b	0.0 ^c	17.6
K _d (%/h)	9.9 ^a	9.1 ^a	5.3 ^b	0.80
T0 (h)	1.8	2.9	2.1	0.65
EDADF (g/kg of ADF)	147 ^c	251 ^b	469 ^a	13.7
EDADF (g/kg of DM)	67 ^a	48 ^b	29 ^c	3.1
RUADF (g/kg of ADF)	853 ^a	749 ^b	531 ^c	13.7
RUADF (g/kg of DM)	396 ^a	142 ^b	33 ^c	14.9

^{a-c}Means within a row with the same superscripts are not significantly different ($P > 0.05$).

¹S = water-soluble fraction; D = potentially degradable fraction; U = undegradable fraction; K_d = degradation rate; T0 = lag time; EDADF = effectively degradable ADF; RUADF = ruminally undegradable ADF.

Digestible Nutrients and Energy Content

As shown in Table 9, no significant differences existed in gross energy among fiber-protein (18.25 MJ/kg of DM), canola meal (18.04 MJ/kg of DM), and soybean meal (17.37 MJ/kg of DM). The lowest ($P < 0.05$) TDN content was observed in fiber-protein (465 g/kg of DM). The TDN value of soybean meal was higher than canola meal (798 vs. 719 g/kg of DM) due to its comparatively higher digestible CP (481 vs. 383 g/kg DM) and NFC (359 vs. 287 g/kg DM) contents. The DE, ME, and NE values estimated for canola meal and soybean meal in this study were similar to those reported in the nutrition composition tables of NRC

(2001). Comparison of energy values among the feed ingredients showed the same pattern for all of the energy values (DE, ME, and NE), with fiber-protein having the lowest ($P < 0.05$) energy values, whereas soybean meal had the highest ($P < 0.05$) values.

Microbial Protein Synthesis and Protein Supply to the Small Intestine

Predicted values of potential true absorbable protein supply to dairy cattle from fiber-protein, canola, and soybean meal as per the DVE/OEB model are given in Table 10. The results show that fiber protein was lower ($P < 0.05$) in fermented OM content (321 g/kg of DM)

Table 9. Truly digestible (td) nutrients, TDN, gross energy (GE), and predicted energy values at maintenance (1×) and production intake levels (3×) of fiber-protein compared with commercial canola meal and soybean meal

Item	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
Truly digestible nutrients (NRC, 2001)				
tdNDF (g/kg of DM)	46 ^a	23 ^b	22 ^b	7.9
tdNFC (g/kg of DM)	198 ^c	287 ^b	359 ^a	13.4
tdCP (g/kg of DM)	278 ^c	383 ^b	481 ^a	11.1
tdFA (g/kg of DM)	05 ^b	43 ^a	3 ^b	3.3
TDN (NRC, 2001)				
TDN _{1×} (g/kg of DM)	465 ^c	719 ^b	798 ^a	22.5
GE (bomb calorimeter ¹)				
GE (MJ/kg of DM)	18.25	18.04	17.37	0.331
Predicted energy value at production intake level 3× for dairy cattle (NRC, 2001)				
DE _{1×} ² (MJ/kg of DM)	9.75 ^c	14.86 ^b	16.83 ^a	0.460
DE _{3×} (MJ/kg of DM)	9.04 ^c	13.77 ^b	15.57 ^a	0.427
ME _{3×} (MJ/kg of DM)	7.24 ^c	12.06 ^b	13.86 ^a	0.431
NE _{3×} (MJ/kg of DM)	4.31 ^c	7.74 ^b	8.96 ^a	0.310
Predicted energy value for beef cattle (NRC, 1996)				
ME (MJ/kg of DM)	7.99 ^c	12.18 ^b	13.81 ^a	0.377
NE _M (MJ/kg of DM)	4.48 ^c	8.20 ^b	9.50 ^a	0.322
NE _G (MJ/kg of DM)	2.18 ^c	5.48 ^b	6.61 ^a	0.285

^{a-c}Means within a row with the same superscripts are not significantly different ($P > 0.05$).

¹Parr 1281 (Parr Instruments Co., Moline, IL).

²DE = digestible energy.

Table 10. Predicted values of potential protein supply to small intestine in dairy cattle from fiber-protein in comparison with commercial canola meal and soybean meal, using the Dutch model and NRC (2001) dairy model

The DVE/OEB model ¹	Feed ingredient			SEM
	Fiber-protein	Canola meal	Soybean meal	
AMCP				
FOM (g/kg of DM)	321 ^b	577 ^a	638 ^a	32.4
MCP _{FOM} (g/kg of DM)	48 ^b	87 ^a	96 ^a	4.9
AMCP (g/kg of DM)	31 ^b	55 ^a	61 ^a	3.1
ENDP (g/kg of DM)	35 ^a	13 ^b	4 ^c	1.8
ARUP				
RUP (g/kg of DM)	187 ^b	163 ^b	235 ^a	10.5
ARUP (g/kg of DM)	62 ^c	138 ^b	235 ^a	5.0
DVE (g/kg of DM) = AMCP + ARUP – ENDP	58 ^c	180 ^b	291 ^a	8.1
OEB (g/kg of DM)	74 ^c	162 ^b	137 ^a	6.9

^{a-c}Means within a row with the same superscripts are not significantly different ($P > 0.05$).

¹DVE = total true protein content potentially absorbable in the small intestine; OEB = degraded protein balance; FOM = fermented OM in the rumen; MCP_{FOM} = microbial protein synthesized in the rumen based on FOM; AMCP = absorbable microbial protein synthesis in the rumen; ENDP = endogenous protein in the small intestine; ARUP = truly absorbable rumen-undegradable protein in the small intestine.

than that of both canola meal (577 g/kg of DM) and soybean meal (638 g/kg of DM). Interference of lignin, which was present at a higher level in fiber-protein, could be attributed to this low microbial degradability in fiber-protein. The difference in fermented OM in the rumen (**FOM**) between canola meal and soybean meal was not significant.

The lower level of FOM, in turn, resulted in a significantly lower predicted values of microbial protein synthesized in the rumen based on FOM (MCP_{FOM}) and absorbable microbial protein synthesis in the rumen in fiber protein (48 and 31 g/kg of DM, respectively) compared with canola meal (87 and 55 g/kg of DM, respectively) and soybean meal (96 and 61 g/kg of DM, respectively). The MCP_{FOM} synthesis and its availability were similar between canola meal and soybean meal.

The RUP content in soybean meal (235 g/kg of DM) was higher ($P < 0.05$) than that of both canola meal (164 g/kg of DM) and fiber-protein (187 g/kg of DM). This was due to a comparatively lower K_d value and larger D fraction of CP in soybean meal. Even though the RUP content in fiber-protein was not different ($P > 0.05$) from canola meal, the truly absorbable RUP in the small intestine (**ARUP**) content in fiber protein (62 g/kg of DM) was significantly lower than that of canola meal (138 g/kg of DM) as well as soybean meal (235 g/kg of DM). In soybean meal, the ARUP content was equal to the RUP content, whereas in fiber-protein, it was approximately one-third of the RUP content. The ARUP content depends on RUP digestibility, which was estimated based on the CP residue remaining after 72-h ruminal incubation. As discussed earlier, CP degradation is negatively affected by ADIP content. It was also noted before that fiber-protein had the highest ADIP content, followed by canola meal, whereas the ADIP content in soybean meal was less than 10 g/kg (Table

2). As such, a lower ARUP content in fiber-protein as well as a totally degradable RUP content in soybean meal can be expected.

The estimated loss of endogenous protein, which occurs during the digestive process due to the extent of undigested DM in a feed, was highest ($P < 0.05$) in fiber-protein (35 g/kg of DM), followed by canola meal (13 g/kg of DM), which in turn, was higher than that of soybean meal (4 g/kg of DM).

As a result of lower absorbable microbial protein synthesis in the rumen and ARUP, along with higher ENDP, the DVE value of fiber-protein (58 g/kg of DM) was predicted to be the lowest ($P < 0.05$) compared to the values in soybean meal and canola meal. The DVE value of canola meal (180 g/kg of DM) was lower ($P < 0.05$) than that of soybean meal (291 g/kg of DM). The results show that all of the feed ingredients exhibited positive OEB values. This shows that the availability of feed protein exceeds the availability of energy (extracted during rumen fermentation) for microbial protein synthesis, indicating a potential N loss in the rumen (Tamminga et al., 1994).

CONCLUSIONS

Fiber-protein, which is the residual portion after aqueous extraction of the soluble fraction from canola meal, retained a sizeable amount of CP and can be classified as a protein supplement. It is also a significant source of fiber. However, as demonstrated by both chemical and in situ analyses, most of the fiber was nondegradable. Unlike protein sources such as canola meal and soybean meal, fiber-protein is higher in non-degradable protein, leading to a lower metabolizable protein content. It is concluded that fiber-protein can be used as a secondary source of protein.

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